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*Dredging Operations Technical Support Program*

# Summary of a Workshop on Interpreting Bioaccumulation Data Collected During Regulatory Evaluations of Dredged Material

*by Todd S. Bridges, David W. Moore, WES*
*Peter Landrum, Great Lakes Environmental Research Laboratory*
*Jerry Neff, Battelle Ocean Sciences*
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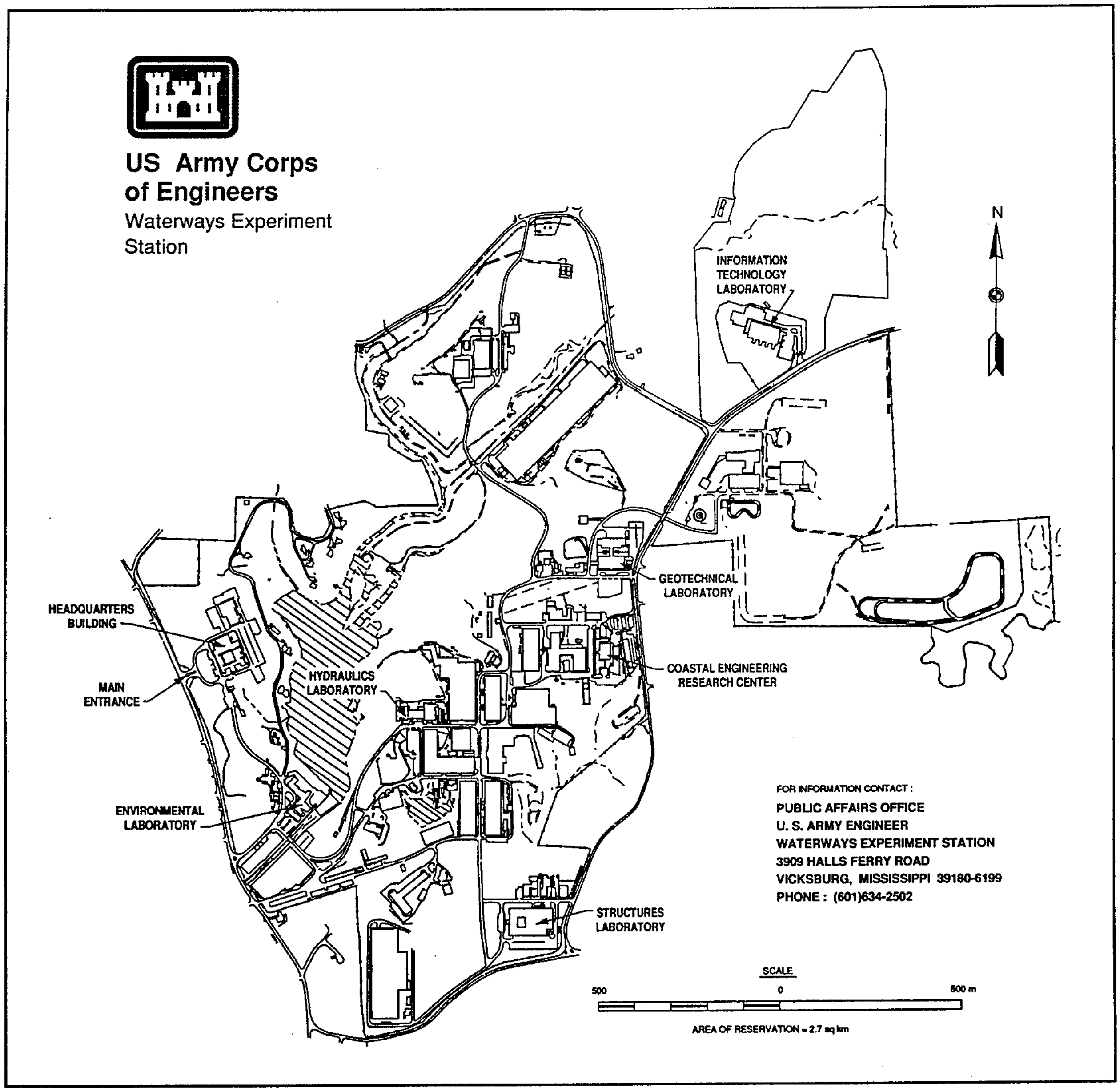


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# Contents

# Preface

The workshop summarized herein was entitled "Interpreting the consequences of bioaccumulation related to dredged material assessment and management activities." The workshop was held in Denver, CO, on 29-31 August 1995. This effort was supported by Headquarters, U.S. Army Corps of Engineers, through the Dredging Operations Technical Support (DOTS) Program. The DOTS program is managed by Mr. Thomas R. Patin. This summary was prepared by compiling written summaries submitted by the chairmen of three separate workgroups: Dr. Peter Landrum, Benthic Workgroup; Dr. Jerry Neff, Fish and Wildlife Workgroup; and Dr. Jerry Cura, Human Health Workgroup. This document does not represent a statement of policy, but an accurate summary of the significant discussions held at the workshop.

This summary report was prepared by Drs. Todd S. Bridges and David W. Moore, Fate and Effects Branch (FEB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES); Dr. Landrum, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, MI; Dr. Neff, Battelle Ocean Sciences, Duxbury, MA; and Dr. Cura, Menzie-Cura and Associates, Inc., Chelmsford, MA. The organizers of this workshop wish to acknowledge and thank each of the workshop participants for their valuable contributions.

The work described herein was performed under the general supervision of Dr. Bobby L. Folsom, Jr., Chief, FEB. The Chief of EPED was Mr. Donald L. Robey, and the Director of EL was Dr. John W. Keeley.

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US Army Corps of Engineers
Waterways Experiment Station

# Environmental Effects of Dredging Programs

## Dredging Operations Technical Support

# Report Summary

***Summary of a Workshop on Interpreting Bioaccumulation Data Collected During Regulatory Evaluations of Dredged Material (MP D-96-1)***

**ISSUE**: Evaluating the environmental consequences of contaminant bioaccumulation resulting from dredged material disposal is a complex technical and regulatory problem. This problem is exacerbated by the high cost of bioaccumulation testing and the lack of explicit guidance on how bioaccumulation data should be interpreted and used within a regulatory program. The way bioaccumulation data are interpreted during evaluations of dredged material must be technically defensible and cost efficient.

**RESEARCH**: In response to problems related to the interpretation of bioaccumulation data, the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (USEPA) held a joint bioaccumulation workshop in Denver, CO, on 29-31 August 1995. The purpose of the workshop was to determine if more effective regulatory guidance could be developed for interpreting the effects of bioaccumulation from data currently collected during evaluations of dredged material. Workshop participants were from the USACE, USEPA, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration (NOAA), Department of Defense, academia, and the private sector.

**SUMMARY**: Short- and long-term recommendations are made for interpreting bioaccumulation data to ensure the protection of human health and aquatic and terrestrial wildlife.

**AVAILABILITY OF REPORT**: The report is available on Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; telephone (601) 634-2355.

To purchase a copy, call the National Technical Information Service (NTIS) at (703) 487-4780. For help in identifying a title for sale, call (703) 487-4780. NTIS report numbers may also be requested from the WES librarians.

**About the Authors:** Drs. Todd S. Bridges and David W. Moore are research biologists in the WES Environmental Laboratory. Dr. Peter Landrum is a supervisory chemist and Head of the Biogeochemical Sciences Division at NOAA's Great Lakes Environmental Research Laboratory. Dr. Jerry Neff is a senior scientist with Battelle Ocean Sciences. Dr. Jerry Cura is a senior scientist with Menzie-Cura and Associates, Inc. For further information about the Dredging Operations Technical Support Program, contact Mr. Thomas R. Patin, Program Manager, at (601) 634-3444.

# 1 Introduction

Evaluating the environmental consequences of contaminant bioaccumulation resulting from dredged material disposal is a complex technical and regulatory problem. This problem is exacerbated by the high cost of bioaccumulation testing and the lack of explicit guidance on how bioaccumulation data should be interpreted and used within a regulatory program.

Bioaccumulation is a measurable phenomenon, rather than an effect. Without specific information about biological effects (e.g., reduced survival, growth, reproduction in animals, cancer risk in humans) resulting from bioaccumulation, it is difficult if not impossible from a regulatory standpoint to objectively determine what level of bioaccumulation constitutes an "unacceptable adverse effect." Existing regulatory guidance attempts to overcome this with two approaches, both of which use low aquatic trophic level organisms and a reference-based comparison. In the first approach, the level of bioaccumulation of a specific contaminant is compared with a numerical effect limit, such as a Food and Drug Administration action level or a fish advisory. If the level of the contaminant in the organism exceeds the numerical limit, it is equated to an "unacceptable adverse effect." If it does not, or there is no numerical limit, the second approach involves a comparison with animals exposed to a reference sediment. If bioaccumulation in the animals exposed to the dredged material exceeds that of animals exposed to the reference, a number of subjective factors are then evaluated to determine whether or not dredged material disposal will result in an "unacceptable adverse effect" (U.S. Environmental Protection Agency (USEPA)/U.S. Army Corps of Engineers (USACE) 1991, 1994).

The first approach is straightforward in that it uses numerical evaluation factors. Because the evaluatory factors in the second approach are subjective, they cannot be consistently applied in the decision-making process. This has created a major problem in the interpretation of bioaccumulation data.

In response to this problem, USACE and USEPA held a joint bioaccumulation workshop in Denver, CO, on 29-31 August 1995. The purpose of the workshop was to determine if more effective regulatory guidance could be developed for interpreting the effects of bioaccumulation from data currently collected during evaluations of dredged material. Workshop participants were from the USACE, USEPA, U.S. Fish and Wildlife Service (USFWS),

National Oceanic and Atmospheric Administration (NOAA), Department of Defense, academia, and the private sector. A list of participants at the workshop is provided in Appendix A. The workshop participants were divided among three workgroups. Each of the workgroups focused on a separate biological system and set of potential receptors. The receptor-defined workgroups included a benthic workgroup, a fish and wildlife workgroup, and a human health workgroup. The charge given to each workgroup was to make recommendations regarding how bioaccumulation data should be used to protect receptors within each system from the potential effects of contaminant bioaccumulation from dredged material. A specific list of questions was supplied to each workgroup to focus discussions; these questions are provided in Appendix B. The significant discussions held and recommendations made by each workgroup are summarized in this report.

# 2 Benthic Workgroup Summary

The benthic workgroup focused its discussion on ways of improving the interpretation of bioaccumulation data during regulatory evaluations of dredged material with regard to effects on benthic communities.

## Bioaccumulative Contaminants of Concern

The discussion began with a focus on currently measured bioaccumulative contaminants of concern (BCCs). The major compound classes currently measured are polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides (primarily chlorinated hydrocarbons including DDT and its degradation products), butyltins, and metals (e.g., mercury, cadmium, lead, arsenic, silver, nickel, zinc, copper, and selenium). The list of BCCs varies regionally. It was the consensus of the discussion group that the list of BCCs should be periodically re-evaluated on a regional basis to determine whether or not specific contaminants should be dropped/added. The group also identified important characteristics that should be considered when selecting BCCs: The contaminant (a) adsorbs to sediment, (b) has a demonstrated potential for bioaccumulation, (c) is persistent in an aquatic environment (e.g., undergoes slow physical, chemical, and/or biotransformation), and (d) has the potential to biomagnify (e.g., $K_{ow} > 6$). When priority pollutant compounds are consistently absent from the bulk sediment chemistry and bioaccumulation data generated for an area, sufficient reason may exist to eliminate these compounds from future analyses.

## End Points

Appropriate end points must be selected before bioaccumulation data can be properly interpreted. The benthic workgroup discussed potential assessment and measurement end points for benthic systems. Assessment end points are "explicit expressions of the environmental values or attributes that are to be protected." Measurement end points are "measurable responses to a stressor that are related to the valued characteristics chosen as assessment end

points." Two potential assessment end points for this system include preservation of benthic community (a) structure and (b) function. A consideration of both direct effects and the potential for indirect effects of the contaminants was deemed important by the group. Direct effects are those that result from direct insult of the contaminant on a particular species, and indirect effects are those that become apparent only through subsequent modification of community structure such that loss of additional populations would occur. However, it was recognized that current measurement end points (i.e., contaminant tissue concentrations) for bioaccumulation were more directly related to community structure, more specifically population structure, than to community function. Factors to be considered when evaluating the potential for adverse effects resulting from bioaccumulation include (a) the likely persistence of the effect, (b) the spatial extent of the effect, and (c) the potential for trophic transfer to produce either a direct or indirect effect on the benthic community. Further, because regulations permit certain short-term impacts within the disposal site, the highest level of protection should be focused on populations outside the disposal site. Management is an option that can limit long-term effects to populations within the disposal site.

With consideration of the above assessment end points, two measurement end point approaches are available to protect the benthic community. The first approach is based on an evaluation of residue-effects data. Current bioaccumulation tests use the test organism as an extraction mechanism. To protect the assessment end point, contaminant specific residue-effects data must be considered. In order to make the linkage between an observed residue level and a biological effect during evaluations of dredged material, development of a residue-effects database is required to relate the measurement and assessment end points. However, such a residue-effects-based approach is chemical specific, is limited by the list of compounds that are selected for evaluation, and cannot currently address the potential for interactions among compounds in complex mixtures.

A second approach is to measure effects directly. This approach requires the use of chronic sublethal bioassays. Bioassays implicitly address the potential additive toxicity of complex mixtures of contaminants in sediments. For such bioassays to be effective, they should incorporate responses that are closely related to population growth and viability, such as individual growth and reproduction. Using such end points, the results of chronic sublethal bioassays are more closely linked to the assessment end points (e.g., alterations in community structure).

Given the emphasis in Federal regulations governing the disposal of dredged material on ensuring the protection of populations and communities of organisms, developing extrapolation techniques for projecting laboratory-measured effects beyond the individual is essential for reasons of scientific and regulatory relevance. Population modeling techniques show particular promise in this regard. These techniques and methods must be emphasized in research efforts in order to ensure their future use in interpreting results of laboratory-based testing.

## Other Bioassay Methods

From a toxicological perspective, bioaccumulation testing is most important for those compounds that take longer to reach toxic thresholds than can currently be assessed via acute bioassays. As new chronic bioassays are developed, the need for bioaccumulation testing may diminish if the assessment end points of importance can be protected. However, from a contaminant management perspective, it may be important to use bioaccumulation testing in conjunction with chronic bioassays to demonstrate that the toxicity observed is the result of exposure to specific contaminants. This type of information may be useful for determining appropriate disposal/management options. As chronic bioassays are developed, tissue residue-effects information must be developed concurrently to advance the ability to interpret bioaccumulation data. In addition to the development of bioassay methods, new analytical methods must be developed to reduce the economic burden of bioaccumulation testing. Emerging techniques, such as the use of immunoassays, may be suitable for measuring bioaccumulation of compound classes, and these methods may well reduce the analytical costs associated with bioaccumulation testing. As other classes of environmentally important toxicological effects are recognized, e.g., endocrine disruption, the compounds causing these effects will need to be included in bioaccumulation testing.

## Test Organisms

There was recognition by the group that the organisms currently employed for bioaccumulation testing may attain doses that are different from those organisms used in current acute or proposed chronic bioassays. An understanding of the differences in the accumulation potential of various test organisms is required to improve the evaluation of bioaccumulation data. Lipid normalization may help in such comparisons of accumulation potentials for organic contaminants. A more empirically based approach will likely be required for measuring metal bioaccumulation potentials. Factors that alter the toxicokinetics of a contaminant may also require the development of empirical relationships even for organic contaminants.

## Short-Term Recommendations

### Method variance and statistical significance

Bioaccumulation testing, as currently performed, uses a fair amount of compositing both of the sediment to be evaluated and the organism tissue to be analyzed. This approach artificially reduces the variance in the data and increases the probability of finding a statistically significant difference between the test sediments and the reference. The true variance of the systems under study needs to be considered to help ensure that tests of statistical significance

identify important effects rather than artifacts. Four approaches were suggested for improving understanding of the system variance. The ideal approach would be to maintain field replicates in each test (as opposed to the current method of compositing) for both project and reference sediments. A second approach would be a one-time study to evaluate the variance of the system by taking multiple samples from the reference site and testing them independently. This variance could then be examined relative to the data generated for a particular site in future tests. A third approach would be to obtain bioaccumulation factors (BAFs) from bioaccumulation assay data for a reference site composite, making the assumption that contaminant bioavailability among reference site samples does not vary substantially. The measured BAF would then be applied to individual replicates of dredged material to generate a range of expected tissue residues as if these samples had been measured independently in a bioaccumulation test. If multiple independent samples of whole sediment chemistry are measured prior to compositing, then the variance could be independently estimated with each bioaccumulation test. The fourth approach for achieving some understanding of the condition and variance of the reference site would be to measure residues in native species sampled from the reference site.

When the estimates of significance are established, it may be useful to set up a table of compounds indicating the magnitude above the reference that bioaccumulation was observed, for example:

| Compound | <2 X | 2-5 X | 5-10 X | >10 X |
|---|---|---|---|---|
| | | | | |

While this does not give an absolute ranking of the ecological importance of the values, it will give an indication of the amount of exceedance relative to the reference and help prioritize contaminants by degree of concern.

### Residue-effects data

Though limited in amount, there are residue-effects data available in the open literature, gray literature, and specific program documents, e.g., Agency for Toxic Substances and Disease Registry (ATSDR) and Superfund. The bioaccumulation test data can be compared with such effects information. It is recommended that a database be established and put in a form that is easily accessed and utilized by Corps of Engineers (CE) Districts during evaluations of bioaccumulation data. Even with such a database, it becomes necessary to evaluate the multiple congeners or compounds present in tissues. Where the toxic mode of action is the same, molar additivity can be assumed. Compounds acting by different modes of action should be evaluated independently at this time. However, the molar sum of all the organic compounds can be evaluated using the narcosis mechanism of action.

In addition to effects data, it was recommended that ambient background tissue concentrations be provided in the database to establish the expected no-effect end of the data. Laboratory-generated no-effect levels should also be included in the database.

### Screening approaches for estimating residue effects

When chronic water concentration/effects values are available, such as Final Chronic Values for Water Quality Criteria or Great Lakes water quality criteria from the Great Lakes Initiative, a potential body residue could be calculated using bioconcentration factors (BCFs). Comparisons of bioaccumulation test data could then be made to such predicted effects levels. This approach assumes equal sensitivity of benthic and pelagic organisms to toxicants. Such equality has been proposed in the technical document for developing sediment quality criteria (USEPA 1993). Calculations based on data from other water column tests could also be used in the same manner as water quality values so long as the tests were of sufficient duration that the assumption of steady state could be made. Obtaining the best BCF value available is critical. However, to be conservative, the lowest BCF should be used to generate the lowest residue potential and the most conservative estimate of an effect concentration. Again, evaluation of multiple toxicants would need to be evaluated through the use of an additivity model in the form of the toxic units approach (Rand and Petrocelli 1985). There are examples of these kinds of calculations for organic and metal contaminants in USEPA (1994).

In a similar fashion, comparative tissue residues could be calculated using existing sediment quality assessment values such as the ERLs (Effects Range Low) and ERMs (Effects Range Medium) (Long et al. 1995), AETs (Apparent Effects Threshold), SLCs (Screening-Level Concentrations) (Neff et al. 1988), and proposed USEPA sediment quality criteria values. This would be done by determining the BAF from the bioaccumulation test and chemistry data for a dredged material. Residue values would then be calculated using all of the sediment quality values available. Because of potential differences in bioavailability among the dredged materials being evaluated and the sediments used during the development of the sediment quality values, multiple sediment quality values must be used to reveal the range in potential response. Due to the presence of multiple contaminants in the sediment, mechanism of action must be addressed as described above.

### Formalize and share evaluation approaches

Considerable variation exists among CE Districts in the methods and procedures used in evaluating bioaccumulation data. It is recommended that such procedures be formalized and shared among the Districts.

## Tier I evaluation

To ensure that potential contaminants are not missed during the evaluation process, a thorough Tier I evaluation, as per USEPA/USACE (1991, 1994), must be performed for the sediments at project sites.

## New approaches

Efforts to glean useful approaches and data from other regulatory programs concerned with contaminant bioaccumulation, e.g., Superfund, are needed. New bioassays are required that more directly relate residues to effects in organisms. For instance, *Macoma* used in a bioaccumulation test could be spawned to see if the accumulated contaminants affect reproduction or the performance of produced larvae. In addition, as new chronic sublethal tests are developed, residue-effects information must be collected concomitantly.

## Continue to develop a database for residue-effects data

As discussed above, it is important that this database be developed, maintained, and updated. This database must include information on background residues and no-effects levels. It is particularly important to establish the residue-response relationship for PCBs, PAHs, metals, and pesticides. Other compound classes that are often problems in sediments must be given priority for establishing residue-response data.

## Training

Training manuals or exercises are required to bring CE District personnel up to date on the state of the art in evaluating bioaccumulation data and its application to regulatory evaluations of dredged material. Included in this is the need to improve the communication between CE Districts and CE/USEPA scientists to identify problems and develop solutions and guidance. There was a recognized need to review existing bioaccumulation data at CE Districts to identify consistent problems and focus the development of appropriate solutions.

## Spatial variability

Focused research is required for the purpose of defining the relative significance of contaminant exposure from a relatively small disposal site with regard to the assessment end points under consideration. Questions related to defining what long-range impacts are expected when contaminant sources are spatially small and populations are widespread must be addressed.

### Bioavailability

Research to develop the links between sediment concentrations and residue effects is needed to improve the understanding of factors that affect the bioavailability of sediment-associated contaminants. Existing data should be analyzed to calculate the variance in biota-sediment accumulation factors (BSAFs) to be used in Tier II of dredged material evaluations (USEPA/USACE 1991, 1994). Important normalizing factors must be identified and incorporated as appropriate.

### Ecological relevance of current bioassays

Research should continue to define the ecological relevance and reliability of currently used sediment bioassays. Experiments designed for the purpose of validating the predictive quality of sediment bioassays will be critical to this effort.

## Long-Term Recommendations

### Data acquisition and research

A long-term commitment to focused research will result in substantially improved procedures for evaluating bioaccumulation test data. A major focus of this research must be the generation of residue-response relationships for chronic/sublethal bioassays. Chemical priorities must reflect the problem chemicals as defined at the regional level. It was recommended that this research include efforts to field verify the predictions/decisions based on this data. The search for new or unexpected bioaccumulating chemicals must be integrated into this effort. It is only with the development and application of chronic/sublethal effects bioassays and the joint application of bioaccumulation studies that such unusual or unexpected contaminants will be identified. If possible, shorter term tests should be developed that provide information equivalent to that produced by sublethal/chronic bioassays, e.g., biomarkers to predict the potential for effects.

Research is needed for defining the relationship between bioaccumulation and sediment contaminant concentrations and the use of normalizing values such as TOC (total organic carbon) and AVS (Acid Volatile Sulfide) and the uncertainty and limitations associated with these methods. This should include the development of additional methods for predicting or estimating the potential for bioaccumulation of metals and organic contaminants beyond the nonpolar organics. Additional screening-level approaches are needed to indicate when bioaccumulation testing is necessary.

There is a continuing need to further the understanding of the physiology of currently used and proposed bioassay organisms. A focus on the exposure conditions experienced by these organisms should be part of this research.

### Quality control

Better understanding of the uncertainty associated with current bioaccumulation tests must be developed, including the development of appropriate quality control. Further, any new test that is developed should be evaluated through round robin testing (to address interlaboratory variability). The laboratories performing bioaccumulation tests must demonstrate their competence to perform the test in a standardized fashion.

# 3 Fish and Wildlife Workgroup Summary

The focus of the fish and wildlife workgroup was on techniques for using bioaccumulation data to protect those organisms not a part of the benthos, namely fish and other aquatic and terrestrial wildlife.

## Definitions

Bioaccumulation is the uptake and retention of a chemical by an organism from all available sources: water, food, sediments, and air. Trophic transfer is the bioaccumulation of a chemical from food. Biomagnification is a special case of bioaccumulation in which the concentration of the contaminant in the tissues of the consumer reaches a concentration that is substantially higher than the average concentration of the contaminant in its prey ([consumer] $>>>$ [prey]). Biomagnification may occur if the uptake rate is much larger than the release rate. Biomagnification in freshwater and marine food webs is usually restricted to highly hydrophobic chemicals ($\log K_{ow} > 6$) or chemicals that bind tightly to tissue macromolecules (e.g., methyl mercury).

## Exposure Pathways

The major mechanism by which contaminated sediments and dredged material may adversely affect fish and wildlife is through bioaccumulation of chemicals from sediments through consumption of contaminated food organisms associated with the contaminated sediments. The processes involved include bioaccumulation, trophic transfer, and possibly biomagnification. Other routes of exposure are possible when dredged material is disposed of at intertidal and upland disposal sites. Exposure to chemical contaminants desorbed and dissolved from contaminated dredged material into the overlying water column or to chemicals adsorbed to resuspended sediment particles was not considered to be a quantitatively important exposure pathway in most cases by members of the discussion group.

## Bioaccumulative Contaminants of Concern

The participants discussed which chemical contaminants, sometimes present at elevated concentrations in dredged material, present the greatest risk of accumulating to toxic levels in fish and wildlife. There was general agreement that, for nonpolar organic chemicals, those with log $K_{ow}$s greater than about 5 have the greatest potential to be bioaccumulated from food; nonpolar organic chemicals with log $K_{ow}$s greater than about 6 have the greatest potential to biomagnify to very high concentrations in top predators, particularly if the top predators are air breathers, such as raptorial birds and fish-eating mammals. Included in this category are many organochlorine compounds, such as the more highly chlorinated polychlorinated biphenyls, and some persistent pesticides, such as DDT.

It is more difficult to identify metals and metalloids with a strong potential to bioaccumulate in aquatic food chains to potentially toxic concentrations. Bioaccumulation of metals does not follow simple partitioning models. Each metal behaves differently, depending on its speciation in marine and freshwater sediments. Those metals that form stable organometal compounds in aquatic environments (e.g., mercury, arsenic, lead, selenium, and tin) have a greater potential to accumulate in food webs than those that do not. Differences in the toxicity of mobile (dissolved, ionized) species of different metals also must be taken into consideration. Some metals, such as arsenic, vanadium, zinc, and selenium, may be selectively accumulated to very high concentrations in tissues of some species of marine or freshwater animals with no apparent toxic effects. Some metals are sequestered in tissues of marine and freshwater organisms in chemical forms that are not harmful to the organisms themselves or their predators (e.g., more than 90 percent of the arsenic in the tissues of marine crustaceans and fish is in the form of nontoxic arsenobetaine). Thus, the metals of concern include those that are frequently present in aquatic environments in highly toxic forms and those that may be transferred in organic forms through aquatic food webs (mercury, cadmium, arsenic, lead, selenium, tin, and a few others). The list of BCCs for fish and wildlife should be limited to those contaminants for which there is substantial evidence for the importance of trophic transfer as a mechanism of bioaccumulation.

## End Points

The workgroup participants discussed which fish and wildlife end points could be most appropriately evaluated using bioaccumulation data. There was general consensus that the primary goal was to protect populations of commercially and recreationally important fish species and intrinsically valuable wildlife (reptiles, birds, and mammals, including threatened and endangered species) from harm. These are the biological resources of concern. The major assessment end point of concern is to ensure the protection of specific fish and wildlife populations, not necessarily protecting against attaining

certain levels of tissue contamination in individual animals. In order to protect biological resources of concern from the adverse effects of contaminated dredged material, the trophic structure of the ecosystem at the disposal site needs to be understood. Attention should be focused on assessing the risk of local population extinction at each level in the trophic web (e.g., forage fish/ invertebrates (herbivores), predatory fish, and birds and mammals). The goal is not so much to maintain stable populations (an unrealistic goal), but to avoid affecting the dynamics of the population due to the presence of chemical contaminants in dredged materials. In order to relate tissue residues of chemical contaminants to effects at the population level, specific information is needed for the resources of concern. The toxicological end points evaluated should be related to effects at the population level (e.g., survival, growth, and reproduction).

Measuring contaminants in eggs of fish-eating birds and livers of fish-eating mammals has been used effectively in studies in the Great Lakes to predict effects of tissue contaminants at the top level of food chains. Critical body residue (CBR) data have been collected and can be used to relate tissue-residue data to biological effects. However, the CBR data are based on responses, usually acute, of individuals and are difficult to extrapolate to populations and communities. The CBR approach should be expanded to include data on tissue-residue levels associated with biological responses such as long-term survival, early development, and reproductive success, in order for such an approach to be of use in interpreting effects at the population level.

There was considerable discussion about what measurement end points to use in assessing risk to fish and wildlife from contaminated dredged material. One approach was to use empirically determined BSAFs, defined as the ratio of the lipid-normalized concentration of a contaminant in the tissues of an aquatic/marine organism to the TOC-normalized concentration in sediments to which the organism was exposed. BSAFs are more reliable predictors of tissue residues when going from sediments to benthic invertebrates than when extrapolating to higher trophic levels. Uncertainty increases with increasing numbers of trophic steps involved in the BSAF estimation.

Considering the uncertainties involved, empirical tests, such as the standard 28-day bioaccumulation test, are the best way to estimate the bioavailability of chemical contaminants associated with dredged materials. There is a need to compile and interpret all the available data from 28-day bioaccumulation tests and other tests that directly measure uptake of contaminants from sediments. These data can be used to estimate ranges of bioavailability (measured as BSAFs) in sediments with different physical and chemical properties. The uncertainty associated with predictions of bioaccumulation based on 28-day tests can then be compared with uncertainties associated with BSAFs derived from other sources. This analysis may be used to decrease the uncertainty of BSAFs.

## Comparative Risk Estimation

Ideally, incremental changes in risk should be measured or predicted by comparing the risks due to dredged material disposal with those produced by other local point and nonpoint sources of chemical contamination. Animals at the disposal site are likely to contain residues in their tissues of the chemical contaminants of concern even before dredged material disposal begins. It is important to determine what these background tissue residues are and what the sources of contamination are. In some areas, such as some parts of the Great Lakes, background concentrations of some chemicals of concern in sediments and tissues already are unacceptable. In such situations, if concentrations of chemicals of concern in dredged material are no higher than those in site sediments, dredged material disposal should not make the situation worse.

## An Example

The Great Lakes Water Quality Initiative was discussed as a possible model of how to relate tissue residues in benthic fauna and sediments to risks to biological resources of concern. The USFWS biological opinion describing this approach estimates the potential effects of environmental contamination on higher trophic levels in aquatic/terrestrial food chains. The receptors of concern include top predatory birds (e.g., eagles and peregrine falcons) and mammals (mink). Steady-state biomagnification factors (BMFs) were determined empirically and used to predict concentrations of contaminants in aquatic media from concentrations in selected tissues of top predators. Chemical contaminant concentrations were measured in eggs of raptorial birds and piping plovers and in mink and otter livers. Contributions to the observed tissue residues from various prey sources were estimated based on knowledge of the foraging biology of the top predators. This approach takes the BSAF model concept to the next level of complexity by incorporating the food web and transfer coefficients for multiple prey species.

This approach can be used to assess risks of contaminated dredged material to the biological resources of concern by use of various transfer coefficients up through the local food web to the species of concern. Tissue residues measured in this way are compared to residue levels associated with toxic responses of relevance to population health (CBR). If the estimated tissue residue levels are an order of magnitude or so lower than the CBR, there is no need to evaluate the dredged material further with respect to risk to fish and wildlife populations. If the estimated tissue residues are similar to or exceed the CBR, more detailed study may be necessary.

## Importance of Spatial Scales

In performing an assessment of this type, it is important to consider that the dredged material disposal site is generally only a small part of the foraging range of the mobile species of concern. Accumulation in the field is likely to be much less than bioaccumulation estimated from equilibrium partitioning models. Dredged materials may move from the disposal site after disposal; foraging animals and top predators may move in and out of the area. Most mobile species probably would use the disposal site only part of the time. However, accumulation of dredged material on the bottom at the disposal site may attract some motile species (the so-called reef effect). There is a need to agree up front on area use factors. It may be necessary to monitor the disposal area to develop use factors for key species of concern. Some populations may use the area of the disposal site on a seasonal basis. Risks associated with chemical contamination of dredged materials at the site will be greater if seasonal use is by life stages that are more sensitive to pollution (e.g., reproductive stages or larvae). It is also necessary to clearly define the size of the population that is of concern. Large, wide-ranging populations are much less at risk from contaminated dredged material than small, localized populations. It also may be necessary to treat dispersive sites differently from nondispersive sites. Consideration should be given to the possibility that multiple disposals of dredged materials at a disposal site may have different long-term, cumulative effects than a single large-disposal event at a site. Multiple disposals are likely to have less than an additive effect on local biological resources of concern.

## A Screening-Level Approach

The participants discussed an approach to screen for the potential for contaminant-related effects on fish and wildlife populations of concern. The analysis is triggered if bioaccumulation of any contaminants of concern from the dredged material is significantly greater than from reference sediment, based on 28-day bioaccumulation tests or BSAFs. In the protocol the investigator will do the following:

*a.* Focus narrowly on the list of contaminants of concern.

*b.* Choose species of concern.

*c.* Determine populations (size and spatial distribution) of concern.

*d.* Determine food web at disposal site.

*e.* Apply BSAFs.

*f.* Assume that the forage area is the disposal site (conservative initial evaluation).

*g.* Compare estimated exposure to toxicity database (e.g., CBRs).

*h.* Interpret effects in terms of population level impacts or human health.

*i.* Assess uncertainty.

*j.* Characterize total and incremental risk.

This screening approach is valuable in that it makes the evaluator think about the whole ecosystem at the disposal site. There is a need to perform a few pilot risk analyses to assess the costs and benefits of the approach. This process will become easier with each successive evaluation. The process requires development of several databases. CE Districts could pool some resources to assemble initial databases. Environmental Impact Statements prepared during dredge material disposal site designation could be used to provide some of the necessary information (e.g., composition of local food webs) with little additional effort. In these model assessments, it is important to keep food web structure simple; three to four trophic levels specific to receptors of concern at the site probably is sufficient.

## Model Validation

Although there is a need to validate the models used to estimate risks posed by contaminants in dredged material, this is very difficult to accomplish. It is always difficult to detect small changes in population health due to a particular human activity because of the wide natural variability in various indicators of the status of natural marine and freshwater populations and communities. Heavily contaminated sediments ordinarily are not considered for open-water disposal, and so the objective of bioaccumulation modeling is to predict ecosystem effects of slightly contaminated dredged materials. Data from the Black Rock Harbor disposal site in central Long Island Sound and the Field Verification Program may be useful for validation of risk models. The New England Division is still monitoring this site. Another way to validate the models may be to perform mesocosm experiments with contaminated dredged materials. This approach has the advantage that contaminated dredged material will not be released to the environment. It may be possible to use semipermeable membrane devices (SPMD) or lipid bags rather than 28-day bioaccumulation tests to predict the bioavailability of nonpolar organic contaminants from dredged materials.

## Available Tools

Several tools are available that may provide some of the information needed to predict residue levels and responses in populations of fish and wildlife based on concentrations of contaminants in dredged material. These tools include the following:

*a.* The Great Lakes Initiative database of BMFs and BAFs in fish and wildlife.

*b.* The USEPA national database of BAFs for uptake of superlipophilic chemicals from water and sediments.

*c.* The U.S. Army Engineer Waterways Experiment Station BSAF database.

## Regulatory Use Requirements

In order for fish and wildlife to be a routine consideration during regulatory evaluations of dredged material, (a) the evaluation procedures must be simple; (b) resources of concern must be defined on a site-specific basis; and (c) a single conceptual model must be developed for deep-water and shallow-water disposal sites.

## Short-Term Recommendations

Short-term recommendations are as follows:

- Review the BSAF, BMF, and BAF databases to characterize the sources of uncertainty in resulting predictions.

- Compare variability of the 28-day test to refined variability of the BSAF database.

- Review historic testing results for synoptic 28-day test results and sediment chemistry data and compare with the BSAF databases.

- Perform a pilot study to validate risk assessment methods at two sites (large and small) to assess the cost and refine the methods.

- Develop a list of contaminants of concern in aquatic food chains with respect to receptors of concern. For metals, it may be necessary to distinguish between freshwater and marine ecosystems.

- Develop a tissue residue database that can be used to show the range of tissue residues of different chemicals in different clean and contaminated marine and freshwater sites.

- Develop a database of trophic transfer coefficients (equivalent to BMFs) for metals of concern.

- Develop a tissue residue-biological effects database to be used in establishing CBRs for chemicals of concern.

- Evaluate the use of semipermeable membrane devices as surrogates for 28-day bioaccumulation bioassays and to monitor transport of chemical contaminants from dredged material disposal sites.

- Develop predictive relationships between the surrogates used in bioaccumulation tests and the receptors of concern.

- Develop methods to use oral dose-based toxicity information with BSAFs to predict effects of contaminant body burdens on fish and wildlife populations. The method may be used with the USEPA Wildlife Exposure Factors Handbook.

- Develop extractive bioassays (e.g., similar to the rat hepatoma test) as surrogates for analytical chemistry for selected contaminants of concern.

# 4 Human Health Workgroup Summary

The human health workgroup focused on the use of bioaccumulation data in developing human health risk assessments at dredged material disposal sites. The group felt that bioaccumulation was the most important process in human exposure pathways at dredged material disposal sites. The participants developed a consensus that the product of the discussions should be to develop two general categories of recommendations: (a) short-term suggestions for integrating bioaccumulation into human health risk assessments and (b) long-term suggestions that define research needs. The short-term suggestions focus on existing tools (tests) in current guidance manuals. The long-term suggestions are concerned with the development of new tools or tests or the need to make significant improvements in existing tools.

The initial questions raised by the group included the following:

*a.* Can something more risk based be done than just comparison to background with bioaccumulation testing?

*b.* Are statistical comparisons of bioaccumulation in dredged material and reference sediment adequate consideration of human health?

*c.* Have the States developed risk assessment tools that may be applied to dredged material disposal issues?

## Exposure Pathways

The workgroup considered the pathways by which humans may be exposed to contaminants from a dredged material disposal site by developing a conceptual model. This approach considered that the primary exposure medium at a disposal site is sediment, and that the primary exposure pathway is bioaccumulation from sediment through one or more trophic levels to fish, shellfish, waterfowl, or mammals to human receptors. These human receptors are likely to be consumers of commercial, recreational, or subsistence catches. The recreational receptors may include people eating piscivorous birds or

diving ducks feeding over or on the disposal site and people eating mammals such as raccoons that may feed on fish or invertebrates from a shallow near-shore site. Subsistence hunters may be exposed through consumption of marine mammals where Federal law provides that certain groups may hunt such animals.

The group considered that direct exposure to sediments through contact was a secondary exposure pathway at most sites. It probably did not occur frequently, but should be considered at shallow sites, confined disposal facilities (CDFs), dispersive disposal sites, or at sites where there are airborne losses from CDFs. Suspended sediment may also be an important medium in small closed systems. In such cases, bioaccumulation from suspended sediment through biota to human receptors should be considered.

## Uncertainties

USEPA Region II has used bioaccumulation data in a risk-based methodology to develop sediment guidance when 28-day bioaccumulation testing shows significant accumulation. This method uses a standards-based USEPA modeling approach and borrows heavily from the Great Lakes Initiative including the Gobas Food Chain Model. This approach often resulted in critical tissue levels that were less than background. The group noted that this result demonstrates the power of BAFs going up a food chain and the necessity of having more precise estimates of such factors when assessing human exposures. In many instances, the human exposure is near or at the top of a marine or aquatic food chain, and uncertainty in BAFs are multiplicative.

## Data Needs and Uncertainties

The workgroup then considered the data needs in reaching an understanding of the primary exposure pathway to humans. There was concern expressed by members of the workgroup regarding how to calculate the initial exposure point concentration (EPC) to which the BAFs will be applied. These concerns included the following:

*a.* How to calculate the projected exposure point concentration in sediment at the proposed disposal site; there was particular concern regarding the effects of dredging, disposal, postdisposal sorting, winnowing, erosion, and degradation on the actual EPC.

*b.* How to account for different foraging areas among various species in the food chain of commercial, recreational, or subsistence catches.

*c.* How to account for the fact that some disposal areas may be an attractant, thus affecting the operational foraging area.

The group also expressed concerns regarding the mechanisms of bioaccumulation and the physiological fate of bioaccumulated compounds. These concerns included the following:

*a.* The formation of metabolites (such as occurs in fish when exposed to PAHs) and the potential to then bioaccumulate the metabolites. Is it possible that carcinogenic or toxic metabolites are being accumulated in the food chains but ignored because they do not initially occur in the sediments?

*b.* Are there seasonal changes in the BAFs?

*c.* Is there differential accumulation of compounds in different tissues of commercial, recreational, or subsistence species? This is particularly important in that humans often do not eat the entire fish, and consumption warnings regarding a particular tissue could be used to limit exposure.

Other concerns included the effects of human behavior on exposure. These included the following:

*a.* The use of information on seasonal consumption of species in developing exposure pathways.

*b.* The effect of the particular chemical form on human physiology as opposed to exposure to an assumed total chemical; for example, is the chemical bioaccumulated in a form that is either nontoxic to humans or a form that they easily excrete?

*c.* What are the synergisms or antagonisms associated with multiple contaminant exposures?

## Risk Assessment Techniques

During the final discussion period, the workgroup focused upon the use of human health risk assessment in dredged material disposal evaluations. The group considered that USEPA is beginning to use probabilistic risk assessment, and that risk assessments at dredged material sites should begin to address this technique as a way to deal with uncertainty.

There was discussion regarding background risk and the use of comparative risk. The suggestion was made that risk at the proposed disposal site should simply be compared to calculated risk at a reference site for siting decisions. This comparison to a reference site would be consistent with the way bioaccumulation data are now evaluated. There was also discussion of whether comparative risk should be used to assess incremental risk above a background sediment or as a method to compare risk from the site with the

total risk an individual receives from all alternate sources of a particular compound.

## Benefits

The group also recognized that human health risk assessment can be applied at two levels: on a site-specific basis and in developing regional guidance. The general consensus of the group was that application of risk assessment techniques and implementation of the workshop recommendations in either case would be able to overcome the delays and costs associated with the current use of bioaccumulation testing. The current use of bioaccumulation testing does not directly apply to human health issues. However, the incorporation of risk assessment methods into the process would result in cost savings in two ways: delays in the permitting process would be shortened, and the development of generic guidance that could be applied on a site-specific basis would avoid the expense of bioaccumulation testing that may not necessarily apply to a specific site or exposure pathway.

## Short-Term Recommendations

The group had several short-term recommendations that apply to compiling and centralizing information useful to human health risk assessors. These include the following:

- Develop an exposure-factors handbook specifically for commercial, subsistence, and recreationally captured species common to dredged material disposal sites. This information should include foraging areas, seasonal migrations, seasonal locations and ranges of sensitive life stages, and other biological characteristics that affect the exposure of such species to contaminants in the marine, estuarine, and freshwater environments. This would be a handbook similar to USEPA's Wildlife Exposure Factors Handbook. The group recognized that much of this information is already available in NOAA publications, USFWS publications, State resource agency publications, and from fishing industry groups.

- Compile BAFs by species, contaminant, and faunal province for commercial, recreational, and subsistence species and their prey. This would be particularly valuable in defining the range of BAFs for species in the sediment-to-human food chain and in identifying data gaps specific to the human food chain components.

- Compile models/methods for projecting EPCs at a proposed disposal site. This compilation should include model characteristics, possible use, and whether the model has been tested at a disposal site. This recommendation is particularly important in the short term given the

group's concern that uncertainties in the initial sediment EPC are magnified in the sediment-to-human food chain by uncertainties in BAFs.

- Compile and maintain a central database of human health risk assessments done at dredged material disposal sites nationwide. This would allow CE Districts to stay current on how other Districts are using risk assessments in the dredged material evaluation process.

- Compile and evaluate information necessary for human health risk assessments during site designation. This recommendation expresses the group's concern that decision makers, risk assessors, and stakeholders who will be using the results of risk assessments be informed and included early in the planning process.

- Develop ecological and human health risk assessment guidance specific for evaluation of risks due to dredged material disposal. This guidance should be generic enough to encompass a wide body of contaminants and be applicable to the various types of dredged material disposal sites encountered among various CE Districts.

- Develop a companion training program in the application of risk assessment guidance for personnel from USEPA, USACE, State agencies, permit applicants, and stakeholders.

- Develop a recognition in risk management for the use, interpretation, and communication of comparative risks at dredged material disposal sites. The implementation of this recommendation should consider incremental risk relative to local or regional background as well as risk relative to the various alternative sources of contaminants unrelated to the disposal site.

- Identify existing centralized, authoritative sources of information on exposure factors, toxicity factors, carcinogenic potency, and BAFs. This information should include how to access these databases. This could be done in the development of guidance for ecological and human health risk assessment.

Note that the human health workgroup recognizes that USEPA recently developed fish consumption factors, and therefore did not make a recommendation regarding this aspect of human exposure.

## Long-Term Recommendations

- Develop distributional data on BAFs and exposure factors for eventual use in probabilistic human health risk assessments. This recommendation recognizes that USEPA is considering the value of probabilistic risk assessment and is already using it to some degree in some regions.

- Identify metabolites of bioaccumulated compounds in the sediment to human pathway that may be toxic or carcinogenic to human receptors.

- Define the chemical forms of contaminants bioaccumulated to human vectors and describe their toxicity or carcinogenicity.

- Describe any differential partitioning of bioaccumulated contaminants among tissues in vectors to humans.

- Conduct field verifications of sediment to human bioaccumulation food chain models.

- Develop methods/models to predict EPCs that recognize transportation, disposal, postdisposal sorting, and in situ degradation of contaminants of concern.

# 5 Future Actions

It is clear, based on discussions and recommendations made during the workshop, that the way in which bioaccumulation data are used and interpreted during regulatory evaluations of dredged material can be substantially improved. The challenge facing the Corps and USEPA is to implement those changes that will secure protection of the environment and human health and streamline the decision-making process.

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# Appendix A
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# Appendix B
# Discussion Items

## Benthic Discussion Items

- What criteria should be used to select potential contaminants of concern in dredged material for benthic receptors.

- Develop a conceptual model that includes the key contaminant exposure pathways between contaminants in dredged material and benthic receptors. Prioritize the pathways by degree of importance.

- Develop a list of appropriate assessment end points for the benthic system. Reminder—assessment end points are "Explicit expressions of the environmental values to be protected."

- Develop a list of appropriate measurement end points for the benthic system. Reminder—measurement end points are "Measurable responses to a stressor that are related to the valued characteristics chosen as assessment end points."

- Is information on the potential for bioaccumulation (measurement end point) necessary to ensure protection of the assessment end points identified above? Will other measurement end points allow adequate protection of the assessment end points in the absence of bioaccumulation data? For example, would chronic sublethal toxicity tests provide adequate protection in the absence of bioaccumulation data?

- Is a 28-day bioaccumulation test always necessary to evaluate the long-term risk to the assessment end points listed above? Could other methods of evaluation, e.g., TBP, BSAF's, and other modeling techniques, be used in place of such laboratory testing? Under what conditions could such evaluations be made in place of laboratory testing? What uncertainties are involved in these evaluation techniques?

- How should data from a bioaccumulation test (measurement end point) be used to make management decisions? How is the link made

between what can be measured (measurement end point) and what one is trying to protect (assessment end point)?

- How should the effects of elevated concentrations of substances in animal tissues be evaluated? How does one determine when the concentration of a substance in animal tissue is ecologically relevant?

- Develop short-term (1- to 2-year) recommendations on how bioaccumulation data should be evaluated from the perspective of benthic receptors.

- What long-term (3- to 5-year) recommendations can be offered on the course of Corps and USEPA bioaccumulation research related to benthic receptors? A prioritized list of issues to be resolved and appropriate experimental approaches for addressing the issues of concern needs to be provided.

## Fish/Wildlife Discussion Items

- What criteria should be used to select potential contaminants of concern in dredged material for fish/wildlife receptors.

- Develop a conceptual model that includes the key contaminant exposure pathways between contaminants in dredged material and fish/wildlife receptors. Prioritize the pathways by degree of importance.

- Develop a list of appropriate assessment end points for the fish/wildlife system. Reminder—assessment end points are "Explicit expressions of the environmental values to be protected."

- Develop a list of appropriate measurement end points for the fish/wildlife system. Reminder—measurement end points are "Measurable responses to a stressor that are related to the valued characteristics chosen as assessment end points."

- Is information on the potential for bioaccumulation (measurement end point) necessary to ensure protection of the assessment end points identified above? Will other measurement end points allow adequate protection of the assessment end points in the absence of bioaccumulation data? For example, would chronic sublethal toxicity tests provide adequate protection in the absence of bioaccumulation data?

- Is a 28-day bioaccumulation test always necessary to evaluate the long-term risk to the assessment end points listed above? Could other methods of evaluation, e.g., TBP, BSAFs, and other modeling techniques, be used in place of such laboratory testing? Under what conditions

could such evaluations be made in place of laboratory testing? What uncertainties are involved in these evaluation techniques?

- How should data from a bioaccumulation test (measurement end point) be used to make management decisions? How is the link made between what is measured (measurement end point) and what one is trying to protect (assessment end point)?

- How should the effects of elevated concentrations of substances in animal tissues be evaluated? How does one determine when the concentration of a substance in animal tissue is ecologically relevant?

- Develop short-term (1- to 2-year) recommendations on how bioaccumulation data should be evaluated from the perspective of fish/wildlife receptors.

- What long-term (3- to 5-year) recommendations can be offered on the course of Corps and USEPA bioaccumulation research related to fish/wildlife receptors? A prioritized list of issues to be resolved and appropriate experimental approaches for addressing the issues of concern needs to be provided.

## Human Health Discussion Items

- What criteria should be used to select potential contaminants of concern in dredged material for human receptors.

- Develop a conceptual model that includes the key contaminant exposure pathways between contaminants in dredged material and human receptors. Prioritize the pathways by degree of importance.

- Is information on the potential for bioaccumulation necessary to ensure protection of human health?

- Is a 28-day bioaccumulation test always necessary to evaluate the long-term risk to humans? Could other methods of evaluation, e.g., TBP, BSAFs, and other modeling techniques, be used in place of such laboratory testing? Under what conditions could such evaluations be made in place of laboratory testing? What uncertainties are involved in these evaluation techniques?

- How should data from a laboratory bioaccumulation test be used to make management decisions regarding the protection of human health? How do we make the link between what we can measure (bioaccumulation) and what we are trying to protect (human health)?

- Develop short-term (1- to 2-year) recommendations on how bioaccumulation data should be evaluated from the perspective of human receptors.

- What long-term (3- to 5-year) recommendations can you offer on the course of Corps and USEPA bioaccumulation research related to human receptors? Provide a prioritized list of issues to be resolved and appropriate experimental approaches for addressing the issues of concern.

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**13. ABSTRACT** *(Maximum 200 words)*

Evaluating the environmental consequences of contaminant bioaccumulation resulting from dredged material disposal is a complex technical and regulatory problem. This problem is exacerbated by the high cost of bioaccumulation testing and the lack of explicit guidance on how bioaccumulation data should be interpreted and used within a regulatory program. The way bioaccumulation data are interpreted during evaluations of dredged material must be technically defensible and cost efficient. In response to problems related to the interpretation of bioaccumulation data, the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (USEPA) held a joint bioaccumulation workshop in Denver, CO, on 29-31 August 1995. The purpose of the workshop was to determine if more effective regulatory guidance could be developed for interpreting the effects of bioaccumulation from data currently collected during evaluations of dredged material. Workshop participants were from the USACE, USEPA, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, Department of Defense, academia, and the private sector. Short- and long-term recommendations are made for interpreting bioaccumulation data to ensure the protection of human health and aquatic and terrestrial wildlife.

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